Development of PMT Clusters for CTA-LST Camera

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Abstract: Following the great success of the current generation Imaging Atmospheric Cherenkov Telescopes (IACTs), a preparation of the next generation VHE gamma-ray observatory Cherenkov Telescope Array (CTA) is in progress. Here we report on the prototype photodetector module for the focal plane instrument of CTA Large Size Telescope (LST). In LST, Cherenkov photons are collected by 23 m reflective mirror and Cherenkov images are measured by ∼2500 photodetector pixels installed in the focal plane camera with a diameter of ∼2.5 m. For the LST camera, we have developed the compact PMT cluster module consisting of seven Hamamatsu R11920-100 PMTs with super bialkali photocathodes, Cockcroft-Walton type high voltage power supplies, preamplifier boards, a slow control board and fast readout electronics with low power consumption. Using this PMT cluster module, high performance Cherenkov camera for CTA-LST can be realized.

Keywords: Imaging Atmospheric Cherenkov Telescopes, Gamma-rays, Focal Plane Instrument, Photodetector

1 Introduction

The Cherenkov Telescope Array (CTA [1]) is a new generation VHE gamma-ray observatory which can achieve higher sensitivity with an order of magnitude compared to the current existing Imaging Atmospheric Cherenkov Telescopes(IACTs). The CTA is planned to be constructed from an array of telescopes with different sized mirrors, large (∼23 m), medium (∼12 m), small (∼4-7 m), which are called LST, MST, SST and SCT, respectively. Among these telescopes, LST (Large Size Telescope) is arranged in the center of the array and plays an important role for low energy gamma-ray observation below 100 GeV, which is the important energy range for studies of pulsars, high-redshift AGNs, GRBs, etc. In the current CTA preparatory phase, detailed studies of LST hardware components are ongoing[2] and some of them technically quite advanced. The focal plane camera[3] is one of the component which has much more advanced structure compared to the current IACTs. In the CTA-LST, ∼2500 photodetector pixels are planned to be installed in a sealed focal plane camera with the temperature controlled by a cooling system to avoid the deterioration of the photodetector modules. The diameter of the camera is about ∼2.5 m and each pixel has ∼0.1 deg field of view. The readout electronics is also planned to be installed inside the camera to avoid the problems caused by the long cabling between the telescope and counting house. To realize a high performance CTA-LST camera and manage the large number of photodetector channels, we are studying a compact photodetector cluster module with high performance and low power consumption. In this paper, we report on the status of the photodetector cluster development for the CTA-LST camera.

2 Development of PMT Cluster

The photodetector module has to be sufficiently high performance to satisfy the requirements from CTA-LST. Compactness and low power consumption are also important due to the limit of the weight and cooling ability. In addition, robustness and low cost for mass production are also necessary. After the research of last years, the current baseline of the photodetector for the CTA-LST camera is a photomultiplier tube (PMT) with a possibility of future upgrade to SiPMs[4]. We have developed the first PMT cluster module consisting of seven PMTs, Cockroft-Walton type high voltage power supplies, preamplifier boards, a slow control board and fast readout electronics. The compactness of the cluster is sufficiently enough to manage installation of several thousands channels. In addition, the cluster has a structure which the PMT can be replaced to an alternative photodetector in a future upgrade. We describe each of the components of this PMT cluster below.

2.1 PMT

A first candidate of the photodetecor for CTA-LST camera is Hamamatsu R11920-100 PMT which consists of 1.5 inch super bialkali photocathode with a concave-convex shape window and 8-stage dynodes. The requirements of the photodetector for CTA-LST camera are as follows: (1) peak quantum efficiency (QE) higher than 35% , (2) lifetime more than 10 years, (3) after pulse probability of less than 2×10^{-4} over 4 ph.e., (4) pulse width of 2.5∼3 ns (FWHM), (5) dynamic range of ∼3000 ph.e., (6) timing resolution faster than 1.3 ns (TTS, 1 ph.e.). The Cherenkov telescope is operated under the night sky background (NSB) therefore points (2)–(4) are crucial. After some improvements of the PMT structure in last years, currently Hamamatsu R11920-100 PMT is satisfying these requirements. Here we have developed a prototype PMT module with the Hamamamtsu R11920-100 PMT. Figure 1 shows developed one PMT module consisting of R11920-100 PMT, a magnetic shield, a high voltage power supply and a preamplifier board. Figure 2 represents the QE of Hamamatsu R11920-100 PMT as a function of the wavelength.

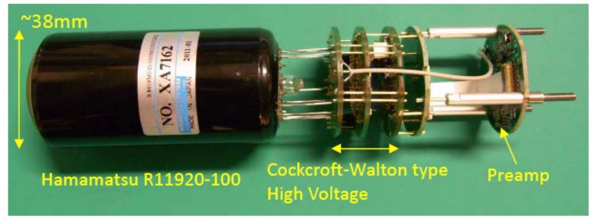

Figure 1: Photograph of the PMT module consisting of the Hamamatsu R11920-100 PMT, a high voltage power supply and a preamplifier board.

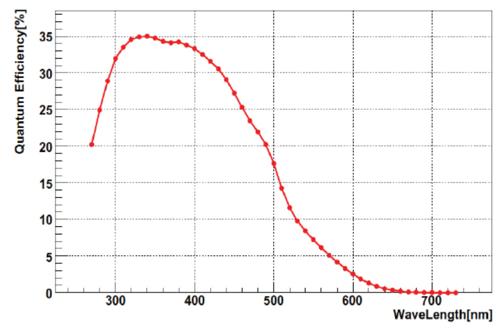

Figure 2: QE of the Hamamatsu R11920-100 PMT as a function of the wavelength.

2.2 High Voltage Power Supply

The Cockcroft-Walton(CW) type high voltage (HV) power supply for the Hamamatsu R11920-100 PMT has been developed by Hamamatsu Photonics K.K.. The structure of the CW-HV is based on MAGIC-II CW-HV [5]. The CW-HV consists of three PCB boards and the power supply voltage is 5V. The HV from 0 ∼ -1.5 kV is controlled by an input range from 0 to 1.5 V and monitored by an output range from 0 to -1.5 V. The voltage between the photocathode and the first dynode is fixed to 300 V by low power Zener diodes for constant single photoelectron distribution. The voltage division for photocathode and 8 dynodes is 300V:1:2:1:1:1:1:2:1. Figure 3 shows the current of CW-HV as a function of HV under dark conditions. The power consumption is ∼ 40 mW maximum. Figure 4 shows the current of CW-HV under the NSB condition simulated by the LED at the PMT operation gain $\sim5\times10^4$.

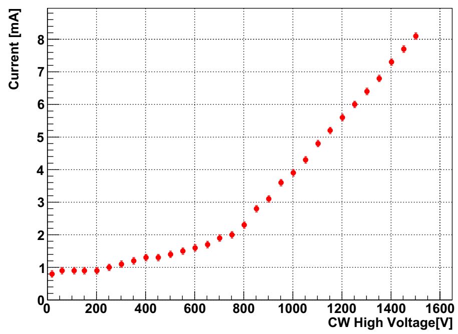

Figure 3: Current of CW-HV as a function of CW voltage under dark condition.

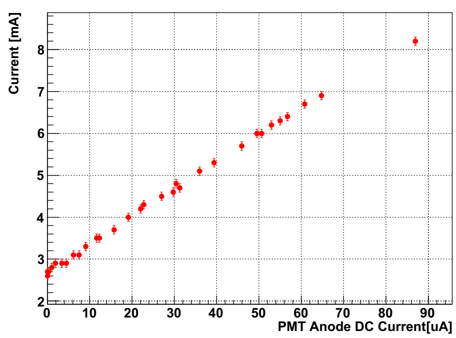

Figure 4: Current of CW-HV as a function of PMT anode DC current.

2.3 Preamplifier

In the CTA-LST camera, the PMT is planned to be operated with a gain of 4×10^4 considering the lifetime under NSB, moonlight or twilight conditions. To match the dynamic range with the readout electronics, the preamplifier board has been developed using the commercial chip (Mini-Circuit, LEE-39+). The circuit design is based on MAGIC-II preamp (SIRENZA, SGA-5586) [5] but here a new chip with lower power consumption is selected to reduce the power consumption in the CTA-LST camera. Figure 5 shows the photograph of the preamplifier board. The circuit for measuring the PMT anode DC current and injecting a the test pulse for the electronics calibration are also implemented. The connector with a pitch of 0.5 mm is used for the connection to the following slow control board. Figure 6 shows an example of the pulse shape of R11920-100 PMT at the output point of the preamplifier board. The total power consumption of the preamplifier board is 183 mW. The PMT signal is amplified by a factor of 10.

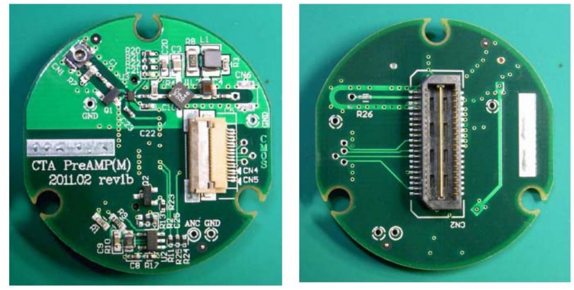

Figure 5: Photograph of the preamplifier board.

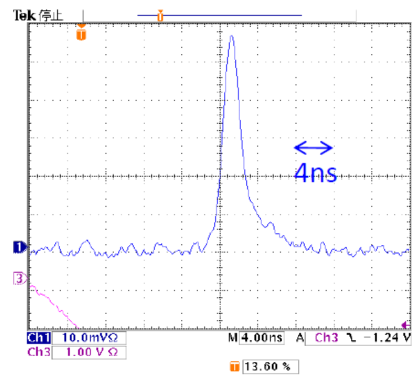

Figure 6: Pulse shape of the PMT signal after the preamplifier board.

2.4 Slow Control Board

The slow control board (SCB) has been developed mainly to control and monitor each PMT. The SCB controls the CW-HV with a 12-bits DAC, monitors both CW-HV and PMT anode DC current ($0 \sim 200$ μA) with a 14-bit ADC. Furthermore it generates the fast test pulse with different attenuations to be injected to the preamplifier board. A temperature sensor, humidity sensor, and a circuit for monitoring both the power voltage and current are also implemented. The power for CW-HV can be switched on or off individually. Figure 7 shows a photograph of the SCB. Seven PMT modules are attached to one side and the readout electronics board is attached to the other side. The PMT signal is fed to the readout board through SCB, therefore the pattern of PMT signal lines is carefully designed with the same layout length in SCB. To control the above mentioned functions, two Complex Programmable Logic Devices (CPLDs, Xilinx XC2C64A) are implemented in SCB. These CPLDs communicate with the Field Programmable Gate Array (FPGA) in the readout electronics board and the data can be sent via Ethernet. The power of SCB is ±3.3 V and 5 V which are common with the readout board. The power consumption of SCB is $\sim$17 mW in standby condition.

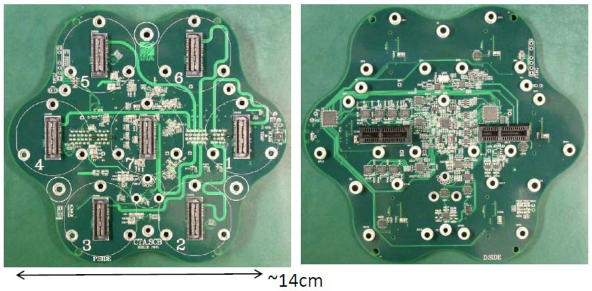

Figure 7: Photographs of the SCB. The PMT side (left) and readout board side (right), respectively.

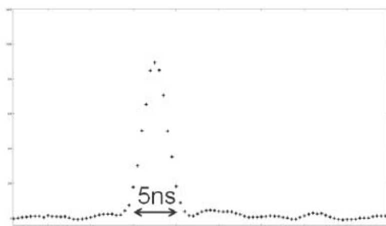

Figure 8: Pulse shape of the PMT signal taken with the DRS4 readout board at 2GS/s sampling.

2.5 Readout Electronics

The fast readout board has been developed using the Domino Ring Sampler (DRS [6]) capacitor array chip. This board consists of eight DRS-version4 (DRS4) chips, ADCs for digitizing a signal stored in the capacitor array in DRS4 at a sampling frequency of 25 MHz, a DAC for control of DRS4, a FPGA (Xilinx Virtex-4), an 18Mbit-SRAM, a Gigabit Ethernet transceiver, and a data I/O connector to the backplane on the left side. In this board, the PMT signal is digitized at a sampling rate of 2GS/s and then transmitted via Gigabit Ethernet. Details are described in separated paper [7]. The PMT signal has been successfully read and transmitted via Gigabit Ethernet. Figure 8 shows the PMT signal recorded by this board.

2.6 Mechanical Structure

Figure 9 shows a photograph of the assembled PMT cluster. Seven PMT modules are attached to the SCB with a pitch of 48 mm and the DRS4 readout board is attached to the backside of SCB. The surface level of seven PMTs is adjusted by spring adjusters installed between the CW-HV and the preamplifier board. A Winston Cone is planned to be installed in front of PMTs to collect Cherenkov light efficiently. The total power consumption and weight of this module are 14 W and 1.3 kg respectively. To be able to operate $\sim$350 PMT clusters in a sealed camera body with constant temperature, we are now designing a cooling system using special heat pipes and a cooling plate.

Figure 9: Photograph of the prototype PMT cluster.

3 Summary

The preparation of the next generation VHE gamma-ray observatory CTA is in progress. Here we reported on the development of the photodetector module for the CTA-LST camera. We have developed the prototype PMT cluster which consists of seven Hamamatsu R11920-100 PMTs, Cockcroft-Walton type high voltage power supplies, preamplifier boards, the slow control board and fast readout electronics. This is the first complete prototype of the photodetector cluster module which is optimized for CTA-LST camera. Several clusters and a small prototype camera will soon be produced to further validate the feasibility to construct the CTA-LST camera by using this cluster.

Acknowledgement

We gratefully acknowledge support from the agencies and organisations listed in this page: http://www.cta-observatory.org/?q=node/22.

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